Uses of Modeling and Simulation in Science and Technology

Office of Naval Research

M&S in S&T

- **Models and simulations serve some functions similar to those of theories in science and technology**
- Brief working definitions
  - **Theory**: a generalization based on observation and experimentation that explains how processes or events are thought to occur
  - **Model**: a representation containing what is thought to be the essential structure and/or function of some object or event
  - **Simulation**: the execution of a model or interacting set of models across time or input manipulations

M&S in S&T

- Modeling and Simulation are used extensively throughout the processes of science and technology, from formulation to product
- Broadly put, models and simulations are used
  (1) As aids to understanding real world phenomena; and
  (2) As techniques for system assessment

M&S as Aids to Understanding (1)

- **Models as conceptual tools summarizing and "explaining" data**
  - Empirical phenomena and the hypothesized causal connections among them can be generalized and abstractly represented in a model
  - In this sense, models can serve both as mnemonic devices and as proposed explanations of observed phenomena
  - Example: the naturalistic decision making model
    - Based on observations of skilled human decision making under stress
    - Decider "recognizes" present situation is similar to past ones, remembers a solution that worked before, checks for essential dissimilarities, and if none, applies old solution

M&S as Aids to Understanding (2)

- **Models as sources of testable predictions**
  - Executable model of a real-world phenomenon is created
  - Model outputs are observed across time or variations in input parameters
  - Its outputs provide empirically testable predictions
  - Empirical observations obtained with modeled phenomena for comparison
  - The result:
    - **Empirical knowledge of the modeled phenomenon is extended**
    - **The model is corroborated, or**
    - **The model fails, requiring modification, abandonment**

M&S as Aids to Understanding (3)

- **Models & simulations as tools to assess completeness, internal consistency of explanation**
  - Does an explanation contain mechanisms sufficient to yield intended outputs? Difficult to tell without implementing is as an executable model and running it
  - Does an explanation use terms and mechanisms in a consistent, non-contradictory way? If not, an executable model of the explanation will not execute.
  - In these ways, models and simulations are powerful techniques for imposing rigor on explanatory concepts in science

M&S as Aids to Understanding (4)

- **Experiments are often run as simulations using models of phenomena rather than with the real world phenomena themselves**
  - A useful approach when empirical evaluation of the modeled phenomena is difficult or impossible (too complex, inaccessible)
  - Example: use of modeled neural networks consisting of 1000's of "neurons" which would be impossible to isolate in actual neural tissue
  - Valuable approach for evaluating assumptions about the properties and causal relatedness of explanatory elements otherwise inaccessible in the real world
  - BUT, this approach is useful only to the extent the models are valid

M&S for System Evaluation in S&T (& R&D) (I)

- **Models and simulations can be used to assess the value-added of (or operational effectiveness) of a potential system prior to the S&T/R&D investment needed to create it**
  - Suppose there are principled reasons to believe development of a certain polarizing technique could increase image contrasts in machine vision systems by x percent in high scatter optical environments (fog)
  - Would an x% increase be cost effective relative to some set of operational requirements or scenarios?
  - Comparisons in system performance modeled with and without the x% increase can be used to determine the scenario-specific value-added by the enhancement prior to the potentially large investments required to develop it

M&S for System Evaluation in S&T (& R&D) (2)

- **Models and simulations can be used to assess the relative merits of alternative system design solutions prior to development**
  - Example: Validated models of human perception and cognition can be used to evaluate the relative merits of alternative interface designs in terms of workload demands and usability, or
  - Mock-up simulations of the alternative interface designs can be used with real human operators or with models of them to compare the designs prior to “bending metal”

M&S for System Evaluation in S&T (& R&D) (3)

- **Mixes of real and simulated system components can be used to evaluate overall performance of incompletely developed systems prior to completion**
  - Example:
    - Hypothesized that combining IR and low-light level CCD technology (yet to be developed) into a single imaging system will yield operationally valuable improvements in imaging under low light level conditions
    - IR imaging system already exists
    - A comparison can be made under a variety of operationally relevant scenarios of performance of
      - IR system alone
      - IR system combined with output from simulated LLL-CCD imaging system
    - Performance improvements with combined system can be evaluated relative to development costs to make decision on S&T investment

M&S for System Evaluation in S&T (& R&D) (4)

- **Models of a system can be used for system evaluation when field tests with the real system are too expensive or dangerous**
  - Example:
    - A new submarine hull design must be evaluated for its structural integrity under conditions of extreme pressure
    - A validated model capturing the relevant structural mechanics of the design can be systematically tested under varying levels of simulated pressure to determine performance operating characteristics without building and subjecting the actual hull design to these conditions

M&S for System Evaluation in S&T (& R&D) (5)

- **System requirements (and design criteria) can be determined by analysis of the performance of a model of the system under simulated conditions**
  - Example:
    - The performance of a weapon or sensor system model can be evaluated under operationally specified conditions to determine the performance parameters of the system required to satisfy defined operational needs
    - These performance parameters (e.g., must have a minimum range of X kms) can then be used to specify system requirements
    - System requirements obviously can be specified without the use of M&S
      - However M&S based analyses may enable more realistic requirements than those generated by less formal methods

Collaborative Opportunities

- **S&T are an integral part of the acquisition process**
  - S&T products can inspire operational needs and requirements
  - Needs and requirements can drive S&T effort
- **These interdependencies have clear collaborative implications and many of them involve M&S**
  - In defining requirements
  - In comparative evaluation of alternative solutions
  - In evaluation of system performance relative to requirements
  - In providing insight into the operational implications of existing or developing technologies
  - In reducing risk associated with system development
  - In reducing the overall cost of acquisitions